



Diverse pathways—common phenomena: comparing transitions of urban rainwater harvesting systems in Stockholm, Berlin and Barcelona

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Urban rainwater management is the terrain of varied initiatives that challenge existing drainage systems. The initiatives that this article refers to as Urban Rainwater Harvesting (URH), promise a more sustainable urban water approach; however, they remain isolated “niche” projects. The article aims to investigate challenges and opportunities for mainstreaming alternative URHs as sociotechnical systems (STS). It identifies six analytical categories: context, actors, instruments, processes/dynamics, outputs and impacts as a framework for the analyses of URH projects in Stockholm, Berlin and Barcelona. Despite the diversity of socio-spatial contexts, driving forces, purposes, instruments used, technical designs and scale of URH projects, relevant factors for a breakthrough of these systems are discussed. Even though URHs have not yet become a common component of rainwater management in any of the cities, context-specific combinations of these factors are found to be essential if these systems are to become complementary options for the sustainable management of rainwater in cities.

Keywords: sociotechnical; transition; urban rainwater harvesting (URH); Stockholm; Berlin; Barcelona

1. Introduction

Current systems of water management in cities are increasingly exposed to a variety of socio-environmental stresses, including climate change, which contest the dominant linear approach of the modern urban water cycle from water supply to water disposal. Urban floods highlight the necessity of alternative approaches that are better prepared for a more sustainable approach to urban water. Urban rainwater management, in particular, is the terrain of multiple and varied initiatives that challenge the dominant large-scale sewer systems and offer a more circular approach to replicating the natural water cycle in which urban runoff may be temporarily stored and/or used within the city, thus reducing the risk of flooding and pollution. In this article we use the expression “Urban Rainwater Harvesting Systems” (URHs) to refer to green, blue and grey

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infrastructures for cities (Agudelo-Vera *et al.* 2012; Rygaard *et al.* 2011), which are foreseen to become a fundamental component of urban water landscapes, utilising rainwater, local surface and, especially, groundwater as well as treated wastewater (Sedlak, 2014). We are aware of the multiplicity of terms regarding urban water flows (Fletcher *et al.* 2015) but we also believe that URH better encapsulates the diverse possibilities for capturing and reusing water in urban contexts. One important question regarding all these alternative URHs is whether they can become a common component of urban drainage policies alongside the more conventional approach, and even dispute the hegemony of the latter, or whether they are likely to remain as mere demonstration projects.

The objective of this article is to investigate challenges and opportunities for mainstreaming alternative URHs in Europe through an inter-city comparison and a cross-case analysis of nine case studies of planning and implementing such systems in Stockholm, Berlin, and Barcelona. We are interested in revealing the wide diversity of pathways towards alternative systems of managing rain in the city—ranging from rainwater tanks for watering gardens to large-scale runoff collection and storage structures in new neighbourhoods—and elucidating how transitions of these sociotechnical systems are conceptualised and critiqued in the literature. In doing so, we identify key elements in the transitions literature applicable to the analysis of URHs. The article is structured as follows. After this introduction, we present our conceptual framework for developing the analysis, which is based primarily on theoretical contributions provided by the transitions approach and its critics. Secondly, we describe the research approach. Thirdly, we outline the nine case studies selected in the three cities that are subsequently interpreted according to analytical categories drawn from the literature review to serve our specific research objectives. Finally, we conclude with the most relevant insights gained from the comparative analysis.

2. Theoretical framework

Despite the growing body of sociotechnical transitions research in empirical and conceptual terms, there is no one coherent transitions theory for analysing and understanding transition trajectories or prospects of STS (Lawhon and Murphy 2012; Markard, Raven, and Truffer 2012). Transitions studies have emphasised different issues—although they substantially overlap—for understanding why (or why not) an STS transition materialises. One of the established frameworks in transitions research focuses on developed and aligned processes at multiple levels (landscape, regime, and niche) that transform an existing STS to another, emphasising niches as drivers for change (Geels 2002, 2004). However, critical studies on the multi-level perspective draw on other disciplines and highlight other complementary terrains for transitions research (e.g. Furlong 2014; Lawhon and Murphy 2012; Coenen, Benneworth, and Truffer 2012; Hodson and Marvin 2010; Raven, Schot, and Berkhout 2012).

This article draws on strands of STS research, green infrastructure, political ecology and human geography pertinent to URHs to develop a theoretical outline for analysing the transition process towards sustainable rainwater management systems. The framework identifies the most important factors that influence the transition process. These issues are largely sociotechnical, covering institutional as well as technical aspects, and are organised into six clusters: context, actors, instruments, processes/dynamics, outputs

and impacts. In the following, we justify the selection of these factors that constitute the analytical framework in terms of relevant strands of the transitions literature.

Scholars of transitions management focus on the niche-regime interaction in response to landscape pressure (Loorbach 2007; Smith 2007). They look at the role of planning and governance in steering STS transitions (Loorbach 2010; Smith, Stirling, and Berkhout 2005). Studies highlight the importance of a receptive *context* for STS transition in terms of awareness, acknowledgment and articulation of pressures; coordination of responses (i.e. building capacity); availability of resources and commitment; cooperative organisations and actors' networks; and coherency of regulations at different spatial scales (Cettner *et al.* 2014; Smith, Stirling, and Berkhout 2005; Ward *et al.* 2012). Pressures do not mechanically affect a regime but need to be taken up, perceived, experienced and translated by actors' agency and intervention in order to exert influence (Dolata 2009; Hodson and Marvin 2010). According to context and governance processes, pressures can be articulated differently. What is at stake in a URH scheme can vary hugely. Depending on local power relations, the aspired transition can, for instance, be about greening neighbourhoods, piloting new technologies or marketing the city (Cole *et al.* 2017). Within a particular urban context, research also highlights the significance of timing and contingent events in shifting political motives that influence and reconfigure STS pathways (García Soler, Moss, and Papasozomenou 2018; Saurí and Palau-Rof 2017).

Further studies emphasise the wide range and role of *actors* and human agency in enabling/stabilising or constraining a breakthrough of a new STS by stressing the role of system users and citizens in relation to problem solving, technology design, purposes and usage (Brown, Farrelly, and Loorbach 2013; Voytenko *et al.* 2016). Within particular institutional settings actors who are (not) involved and their (non-)alignment play important roles in fostering, hampering or influencing STS transitional processes (Brown, Farrelly, and Loorbach 2013). In planning and designing processes of decentralised STS, such as URH, the role of citizens is particularly emphasised. Self-representation of citizens' interests and values can have a two-fold effect. Citizens' participation advances pro-environmental communal attitudes and creates new forms of environmental identity in governance arrangements with justice implications (Agrawal 2005, Button 2017; Cousins 2018). It can also develop systems that are more compatible with local needs and are yet adaptable as needs change (Furlong 2011). Furthermore, actors' attributes in terms of social power and influence, knowledge, expertise, cognitive capacity, trust and reputation are significant factors (Bos and Brown 2012; Brown, Farrelly, and Loorbach 2013; Dolata 2009; Luederitz *et al.* 2017). However, the decision on what actors and whose interests to include is a complex one (Cousins 2017; Karvonen 2011), significantly shaping rainwater management transition pathways.

Transitions research also emphasises the role of *instruments* applied to promote STS transitions (Loorbach 2010). Studies highlight the necessity of providing a space—an arena for actors' networking and experimentation—for the development of niches, experimentation and learning (Bos and Brown 2012; Karvonen 2011; Luederitz *et al.* 2017). While niches are often defined as a protected space for the development of an alternative technology (Schot and Geels 2008), other studies consider niches as a space for societal innovations and policy design (Loorbach and Rotmans 2010; Moore *et al.* 2014; van der Brugge and de Graaf 2010). Of more significance is the ability of a space to challenge the contemporary practices of a regime and provide connections between actors, levels, and resources (Brown, Farrelly, and Loorbach 2013; Karvonen 2011). Studies also point to other important tools. Funding programmes, financial incentives,

the development of visions and transition scenarios, operational goals and monitoring schemes for evaluation are crucial instruments for achieving sociotechnical transformation (Loorbach 2010). Legal instruments can be used to facilitate transition, but they can also create institutional complexity, new bureaucratic actors and potential points of friction, serving as disincentives to rainwater harvesting (Meehan and Moore 2014).

Scholars also argue the significance of societal and political *processes* in specific locations and across scales as constitutive of niche-regime reconfiguration and transition trajectories (Coenen, Benneworth, and Truffer 2012; Hodson and Marvin 2010; Raven, Schot, and Berkhout 2012). Successful sociotechnical change requires bridging organisations and strategic leadership that are capable of mobilising collaborative arrangements and mediating between diverse social interests and competing priorities of innovation (Dolata 2009; Hodson and Marvin 2010; Voytenko *et al.* 2016). Some studies describe an STS transition as a long-term, interactive and reflexive governance process of collective learning for dealing with complexity and uncertainty (Hodson and Marvin 2010; Voß, Smith, and Grin 2009; Voß and Bornemann 2011). Other studies seek to refine our understanding of how system change evolves and describe transition processes in terms of multiphase *dynamics*. These have been described in various ways as pre-development, take-off, acceleration and stabilisation (Brown, Farrelly, and Loorbach 2013); transformation, de-/re-alignment, substitution and reconfiguration (Geels and Schot 2007); or deepening, broadening and up-scaling (Bos and Brown 2012). These phases, however, should not be understood in terms of linear pathways towards system change. Rainwater management is a terrain permeated by societal power and political contestation and can be captured by particular interests (Arabindoo 2011; Button 2017; Cousins 2017). STS transition is, therefore, often messy and can lead to different pathways of reconfiguration, stagnation and coexistence, as well as system change (Bos and Brown 2012; Dolata 2009; Furlong 2014; van der Brugge, Rotmans, and Loorbach 2005).

The literature emphasises that an STS transition is not only about technology transformation, but also societal change (Brown and Farrelly 2009; Kemp, Loorbach, and Rotmans 2007; Loorbach 2007; Luederitz *et al.* 2017). Social change entails new forms of knowledge, politics and institutional regulation, but can also change communities' attitudes to the environment and generate novel modes of urban environmental citizenship (Agrawal 2005, Cousins 2018; Meehan 2014). When considering *outputs* of URH, therefore, attention needs to be paid not only to changes to urban water flows, but also to the contribution of URH schemes to social learning, knowledge generation and institutionalised forms of structural change (Bos and Brown 2012; Dolata 2009; Kemp, Loorbach, and Rotmans 2007; van der Brugge, Rotmans, and Loorbach 2005).

Impacts are long-term and broader results from processes of dissemination of a new STS that go beyond the scope of experimentation. A sociotechnical transition stabilises when a new STS mainstreams through replication and/or up-scaling in the same context or via transferability to other contexts (Luederitz *et al.* 2017). Due to their early emergence in isolated contexts, most of the literature addresses other long-term sustainability impacts in abstract terms. These systems promise a broader range of environmental and socio-economic services and values (Deak and Bucht 2011; Echols 2007). At the level of cities, these systems can help restore the urban water balance (Bell 2015; Deak and Bucht 2011), serve as multi-functional ecosystems and render the urban water cycle more resilient to the impacts of climate change (van der Brugge, Rotmans, and Loorbach 2005; Voytenko *et al.* 2016).

3. Research approach

Three European cities were selected for analysis on the basis of their pioneering roles in promoting URH in their respective countries over a significant period of time. The cities were also chosen to reflect a variety of approaches to URH that emerged from their specific sociotechnical, environmental and political-institutional contexts. Stockholm represents a city reliant on urban planning and urban regeneration to promote URH. Berlin has cultivated a variety of public, commercial and grassroots URH projects for decades. Barcelona is distinctive for the institutional innovations it has mobilised to combat urban water shortages with URH.

Three URH projects were selected in each city according to their value in illustrating five core dimensions: ownership, scale, temporality, spatiality, form and potential for mainstreaming (Table 1). These dimensions were selected to ensure a wide variety of schemes was included, to capture the key distinguishing features of the schemes and to include schemes with the potential for upscaling or replication. We acknowledge the complexities involved in comparing nine cases of different variables and scales. However, such an approach has benefits in terms of being able to systematically analyse and understand the similarities and differences of very different URH projects in diverse cities.

Table 1. The applied criteria (and sub-criteria) for the selection of the nine case studies.

City	Project	Selection criteria	Ownership/ Use			Scale		Temporality		Spatiality (Location)			Form		Potential for mainstreaming	
			Public	Commercial	Residential	Large urban development	Small/Individual building	Established	Ongoing	Central	Suburban (periphery)	Neighbourhood (localised)	Linear	Up-scaling	Replication	Transferability
Stockholm	Hammarby		✓		✓	✓		✓		✓		✓				✓
	Sjöstad															
	Årstafältet		✓		✓	✓			✓		✓	✓		✓		
	Hornsgatan		✓					✓		✓			✓		✓	✓
Berlin	Berliner Strasse 88		✓			✓		✓			✓	✓				✓
	IKEA			✓		✓		✓		✓		✓			✓	
	Lichtenberg															
	Sonnig				✓		✓	✓		✓		✓			✓	
	Wonnig															
Barcelona	Jardinet del Pedró		✓				✓	✓		✓		✓			✓	
	Can Cortada		✓			✓		✓		✓		✓		✓		
	Sant Cugat				✓	✓			✓		✓	✓				✓

The research was conducted along a systematic approach for case selection, data collection and analysis, described in Figure 1. As illustrated in this diagram, primarily

qualitative methods were applied to analyse the available written documentation on each city and its three selected URH schemes, as well as one-to-one interviews held with project managers, city officials, water utilities, residents, consultants and local NGOs. To ensure coherence across the cases and cities, a catalogue of 46 questions categorised along the multiple *research themes* described in Figure 1 was used to guide the data collection and analysis. These themes correspond to the six analytical categories defining the theoretical framework of the article.

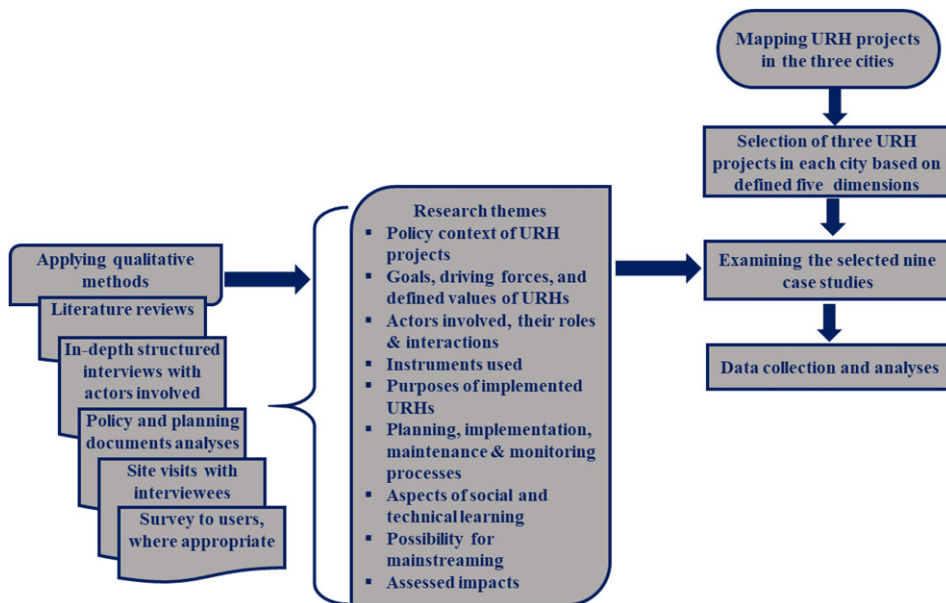


Figure 1. Flow chart describing the applied research methodology.

4. Brief description of the case studies and main findings

4.1. Stockholm

Hammarby Sjöstad (HS) is a large urban development project originally planned to regenerate an old industrial harbour into a modern urban area in the early 1990s. Plans, however, altered. The city council decided to plan HS as a sustainable urban district due to the requirements of the bid for hosting the 2004 Summer Olympic Games. The city lost the bid but maintained the idea due to other driving forces. The city—influenced by local interest groups and the Agenda 21 conference in 1992—was keen to play a key role in establishing a model for sustainable urban districts, which would work locally and globally and enhance Swedish companies' access to world markets (Ranhagen 2013). At that time, pressures on rainwater drainage systems and climate change impacts were not common concerns. However, the need to implement ambitious URH projects to enhance the environmental performance of urban space was recognised. Nevertheless, because of the risk of water leakage into houses, ambitions were lowered. Three innovative, large-scale URH facilities were planned and constructed in HS: a water canal of 800-metre length in a park in “Sickla Kaj” as

integrated and visible blue-green systems, sedimentation basins connected to a small wetland in “Mårtensdal” and an integrated park-wetland designed as stair gardens. The general aim of these facilities is to deal with rainwater and runoff, reduce the overload on the existing drainage system and improve urban attractiveness.

Årstafältet (ÅF) is a large open field and valley located in a suburb in southern Stockholm. Based on a proposal by the Stockholm water company (SWC) and in collaboration with city development planners, URH facilities were constructed (2005–2008) as part of the original plan of ÅF, the Landscape Park (LP). These facilities consist of a stormwater pond, a small stream “Valla”, a distribution ditch, surface screens, vegetated soil beds and water steps. The purpose of these facilities has been to reduce the water load and risk of overflows, clean the water and restore the dry stream, “Bäckravin”, in addition to biodiversity, cultural and pedagogical benefits. As demand for housing grew, the plan of LP was modified. In 2006, the city decided to build urban settlements with a focus on sociotope and biotope values. Part of the field where URH facilities are located will be transformed into the City Park, which includes enlarging the water pond from three to seventeen hectares. The stream will be redesigned into three water ponds and merge into one watercourse. The implementation of the City Park detailed plan commenced in late 2017; the entire project is planned to be completed in 2030. URH facilities aim to deal with rainwater and runoff in the area and the surrounding neighbourhood, as well as generating environmental and social improvements.

Hornsgatan (HG) is a long, major commercial street in Stockholm with air pollution levels higher than permitted by EU regulations. In response to political pressure to resolve the problem, the Traffic Administration (TA) proposed a plan to plant trees in ‘beds’ along the pavements of the street to improve urban air quality and reduce pollution. Tree-bed planting consists of three layers of structural soil (soil, carbon, and crushed rock or recycled concrete). The mixture stabilises the soil and creates good growing conditions for trees, cleans infiltrated water and reduces the risk of damage from roots to underground systems. The air pollution problem was resolved by prohibiting cars with studded tires from entering the avenue. Nevertheless, the city council approved the plan for the environmental rehabilitation of the street. The project is completed. Besides various benefits (safety, security for pedestrians, improved air quality, open areas), an important side effect of the tree-planting was the need for water collected from runoff and rooftops around the street. A tree-planting technique using innovative soil structure techniques has thus become a complementary system for the treatment of urban rain and runoff, but in a sustainable way, also improving other urban quality aspects.

4.2. Berlin

The *Berliner Strasse 88* (BS88) settlement is a major housing project that was planned and implemented by the city and borough authorities between the late 1980s and early 1990s as part of a programme to promote ecological measures in social housing. It is located in Zehlendorf, an affluent and green area in south-western Berlin. The housing settlement’s objectives were to respond to the housing crisis of the then West Berlin, present Berlin as a pioneer of green buildings and to illustrate how ecological design could be incorporated into social building and be made available and accessible to less wealthy sections of the population. Rainwater collected from the settlement’s rooftops

is used exclusively for the outdoor green areas. Once filtered, the water is pressurised and pumped to taps that are used to water the green areas. The cisterns' overflow is linked to the public garden, located in the centre of the settlement. Zehlendorf borough was assigned a key role in the construction and maintenance of the public spaces that are situated within the settlement and three companies (one of which is now privatised) constructed and operated the settlement. No assessment of how the rainwater technologies have influenced water consumption has taken place since the project's completion. As the residents testify, the ambiguous distribution of responsibilities and liabilities on the site has led to suboptimal operation of the rainwater harvesting system. It has been left to the residents to maintain the system in the area that is owned by the privatised housing company.

Sonnig Wonnig (SW) is an apartment building refurbished by a planner and an architect, with the aim of illustrating that living in an ecologically sustainable way is technologically feasible and economically viable in an urban setting. It is located in Lichtenberg, a traditionally industrial borough to the east of the city centre that, following reunification in 1990, has suffered from de-industrialisation and high levels of unemployment and a subsequent bad reputation. The Lichtenberg borough administration has been highly supportive, as the project fits into its plan to improve Lichtenberg's image by greening the urban environment and attracting young families. They facilitated the renovation process, issued the necessary permits and enabled some funding, in the form of a grant under the "Social Urban Renewal" programme in exchange for certain quality standards and legally binding maximum rents. The rainwater component of SW comprises a complex, customised system of collecting, treating and reusing water (rainwater and greywater), and is especially designed for the refurbished building. The only water discharged to the public sewer is black water mixed with some waste kitchen water. Over 15 years after its completion the project is fully functional—technically, economically and socially. The combined effect of rainwater reuse and water conservation measures has drastically reduced the use of drinking water (for other purposes) by 85%. The residents save considerably on rainwater, wastewater and drinking water fees. Rents have been kept low and affordable, as intended, which highlights the social component of the project.

The *IKEA Lichtenberg* (IL) project, constructed in 2010, is IKEA's branch in the borough of Lichtenberg. It is part of Berlin EastSide, Berlin's largest industrial and commercial area and a private-public-partnership shared by two boroughs: Lichtenberg and Marzahn-Hellersdorf. It is the most sustainable IKEA building in Europe and is primarily focused on energy efficiency—notably solar power and using heat from wastewater. It is intended to act as a showcase for IKEA's commitment to environmental and climate protection. For the two borough administrations, this IKEA branch contributes to making the area more attractive for commerce and industry, which further nurtures a positive environmental image. Rainwater is collected from the roof of the store by inlets and directed to an underground concrete cistern. Before entering the retention tank, the rainwater is filtered twice and then used for flushing all the store's toilets and for watering the plants in the store's greenhouse. With this rainwater harvesting and reuse system, IKEA has managed to reduce its drinking water use by an estimated 50%. Furthermore, the URH measures at IKEA have helped the company save costs on water consumption and rainwater disposal and have promoted its green image.

4.3. Barcelona

The *Jardinet del Pedró* (JdP) is a vertical garden placed on a remodelled dividing wall in El Pedró square, located in the Raval neighbourhood, one of the oldest and densest of Barcelona. The purpose was to solve an urban problem with a sustainable project and improve the quality of the public space. Rainwater is harvested from the roof of the building where the vertical garden is installed and collected in a tank located on the ground level. The energy needed to pump water from the tank to the upper part of the garden comes from two solar panels located in the roof of the theatre of Raval. The Institute for Urban Landscape of Barcelona designed the garden with the participation of city agencies for water and energy, as well as the Raval district and a number of private partners. After some initial problems (leaks from the irrigation system that produced damp walls in the building), the project is now highly praised by building dwellers and neighbours. The success of this project led to the development of a standard vertical garden economically viable and easy to install. The JdP provides social and environmental benefits in one area lacking public green space and has been proposed as a model for similar projects in the city.

Can Cortada (CC) is a public space development around a new public housing project in the north of Barcelona that includes URH to manage drainage. The main objective of this system is to avoid flooding and sewer saturation through draining pavements, retention ponds and drainage wells. Permeable pavements convey runoff water towards ponds covered with vegetation, or with gravel and sand, that enable rapid infiltration into the local aquifer. Runoff is captured near its source before reaching the sewers and only in exceptional periods of rainfall intensity is excess runoff diverted to the main sewer. The project was designed by the Department of Urban Planning for Barcelona with the collaboration of the Park Service. CC may signal a change of professional opinion regarding URH in Barcelona. The initial lack of trust in these systems as effective ways to manage floodwaters prompted the water company to build a sewer next to the system because of low expectations about the ability of the latter to contain flooding. However, CC has been used as a model to draft a code of "Good Practices" regarding the development of URH for managing rainwater drainage in the city.

In 2002, *Sant Cugat del Vallès* (SCdV), a suburban town located in the Metropolitan Area of Barcelona, pioneered the adoption of a municipal water savings ordinance in Catalonia and Spain. This ordinance, driven by high domestic water consumption in the city, prescribed various measures to save water through the application of appropriate technologies and the use of alternative sources. The ordinance (modified after the drought of 2008) stated that all new buildings with garden areas larger than 300 m² had to be equipped with a rainwater harvesting system. Questionnaire results have shown that the systems are highly valued by households for non-potable water uses, especially garden irrigation, confirming the interest and support of public water policies for this resource. Water savings translated into lower water bills is the positive aspect most valued by respondents. From this study, it could be deduced that certain environmental policies, such as the implementation of URH systems, need to be enforced first by mandatory means in order to gain acceptance by the public.

5. Comparative analysis

The following section looks across the nine cases, exploring the similarities and differences between them. This comparative analysis is structured according to the six

Table 2: Summarising key findings using the theoretical framework

SH	Context	<ul style="list-style-type: none">• Altered plans according to shifted goals but strong political, financial and legal support, and commitment by the city• The city pushed for planning and implementation of URHs• The city council and administrations acted as a collective agency• A project organisation and a steering team mediating between actors involved and their interests• The water utility (SWC) and consultant firms (developers, designers, construction)
	Actors	
	Instruments	<ul style="list-style-type: none">• Project organisation, envisioning, the Environmental Programme (EP), transition scenarios and measurable operational goals• Master, statutory and detailed plans decided through competition• Strategically led by a skilful and influential project team selected by the city
	Processes/ dynamics	<ul style="list-style-type: none">• A space for collaborative, deliberative, reflexive and democratic planning processes• SWC has an operational role and was less influential in planning and designing processes of URH projects than planners• The lack of appropriate maintenance or monitoring schemes compromised social and technical learning
	Outputs	<ul style="list-style-type: none">• URH projects acted as experiments for building knowledge, though fragmented (which undermined systematic learning)• Developed a cross-sector collaboration planning model that was not institutionalised
	Impacts	<ul style="list-style-type: none">• The planning model is transferred into other global contexts and has become a source of inspiration to many other similar large development projects (e.g. Royal Sea Port, Vasastaden, Hagastaden, Alvsjö)
Stockholm	Context	<ul style="list-style-type: none">• Legislation for sustainable approaches of treating rainwater• Strong financial support and commitment for promoting ambitious URH projects in terms of scale and quality• The city administrations, Stockholm Water Company (SWC), consultancy firms (urban design, engineering and architecture), Swedish University of Agriculture Science (SLU) and nurseries
	Actors	
	Instruments	<ul style="list-style-type: none">• International competition for master planning, envisioning and detailed plans
	Processes/ dynamics	<ul style="list-style-type: none">• Altered plans according to shifted goals• A space for collaborative, deliberative, reflexive and democratic planning processes• SWC was not involved at the programme level and not directly involved in defining the purposes and designing of URHs• Who should maintain what and technical uncertainty (e.g. water flow and efficiency) are still significant challenges
	Outputs	<ul style="list-style-type: none">• Cross-sector collaboration (water utility and landscape planners) is vital but social learning is not formalised or applied
	Impacts	<ul style="list-style-type: none">• The project is still undergoing implementation
HG	Context	<ul style="list-style-type: none">• The city recognised the need to comply with the EU-regulation for air pollution and pushed the TA to deal with the issue• Strong municipal political and financial support and commitment• The city council, Traffic and Environmental administrations, SWC for reallocation of underground water pipes only, contractors, constructors, and lately, the Swedish University of Agriculture for the assessment of tree-planting impacts
	Actors	
	Instruments	<ul style="list-style-type: none">• Tree-planting plan, developed knowledge by the TA, and drawings for the structured soil construction
	Processes/ dynamics	<ul style="list-style-type: none">• Individual agency (from the TA) who developed knowledge and promoted the tree-planting idea and its implementation• Strong political advocacy and financial commitment by the city overcame operational challenges
	Outputs	<ul style="list-style-type: none">• A new tree-bed technique for structured soil using recycled materials and biochar was developed
	Impacts	<ul style="list-style-type: none">• A joint technical learning-by-doing process among planners, civil engineers and constructors• Standardisation and replication of the developed technique; used as a showcase for knowledge transferability• Improving urban quality aspects. The TA with the help of SLU is measuring the economic and environmental benefits

(Continued)

BS88	Context	<ul style="list-style-type: none"> • Social housing in a well-off borough with no water-related problems • Strong political, financial and legal support and commitment initially • Initially, the Berlin Senate and borough administration
	Actors	<ul style="list-style-type: none"> • Two public and one private housing association • Funded through federal and Berlin-state programmes and housing companies
	Instruments	<ul style="list-style-type: none"> • First time introduction of ecological criteria for funding
	Processes/ dynamics	<ul style="list-style-type: none"> • Initiated by the Berlin Senate, top-down • Ambiguous distribution of responsibilities led to suboptimal operation • Following privatisation of one of the three housing associations residents took over maintenance of parts of the settlement • After re-unification of Berlin and its subsequent budget crisis, projects of this scale and type were not replicated and the Senate ended its financial support of the project
	Outputs Impacts	<ul style="list-style-type: none"> • No assessment of the effect URH technologies had on water consumption conducted • No particular impacts measured or assessed
SW Berlin	Context	<ul style="list-style-type: none"> • Bottom-up initiative to refurbish an apartment building in Lichtenberg • An industrial borough with an ageing population and high unemployment
	Actors	<ul style="list-style-type: none"> • Endorsed by the borough • Two initiators – an architect and a planner • Borough of Lichtenberg
	Instruments Processes/ dynamics	<ul style="list-style-type: none"> • Some funding received through the “Social Urban Renewal” plan, with the support of the borough • Grassroots project, with the explicit support of the borough
	Outputs	<ul style="list-style-type: none"> • Aims of both main actors coincided, allowing for a collaborative process with active participation and inclusion of residents • Fully functional, in economic, technical and social terms • Combination of water reuse and conservation measures led to an 85% reduction in water use
	Impacts	<ul style="list-style-type: none"> • Rents have been kept low and affordable • Borough now more open for similar projects; however, rainwater regulations have since become stricter and less conducive to innovative technologies
II	Context	<ul style="list-style-type: none"> • Commercial project, initiated by IKEA Sweden and its German subsidiary • Located in the industrial boroughs of Lichtenberg and Marzahn-Hellersdorf, part of Berlin’s largest commercial area
	Actors	<ul style="list-style-type: none"> • Public-private partnership • IKEA Sweden and its subsidiaries
	Instruments	<ul style="list-style-type: none"> • Two boroughs and Berlin Senate (issuing permits)
	Processes/ dynamics	<ul style="list-style-type: none"> • A split wastewater tariff (with lower payments for run-off from permeable surfaces) was an incentive for retaining water on site
	Outputs Impacts	<ul style="list-style-type: none"> • Internal IKEA process, with little interaction or consultation with the boroughs • Well incorporated in the Berlin East Side commercial area • Reduction of both energy and water consumption • Borough officials encourage other developers to follow IKEA’s example, but no measurable impact

(Continued)

JdP	Context	<ul style="list-style-type: none">• Vertical garden on a dividing wall in a dense neighbourhood lacking green areas
	Actors	<ul style="list-style-type: none">• Office for the Improvement of the Urban Landscape (Barcelona City Council)• Other city council agencies (water, energy, parks and gardens)
	Instruments	<ul style="list-style-type: none">• Self-funded through commercial advertising
	Processes/ dynamics	<ul style="list-style-type: none">• Initiated by the Barcelona city council, top-down• Part of a programme to improve urban landscape after the redevelopment of El Pedró square• Integration of URH with renewable energy• After some initial problems, well received by owners and neighbours
	Outputs	<ul style="list-style-type: none">• New green area
Barcelona CC	Impacts	<ul style="list-style-type: none">• Model for replication on other dividing walls in Barcelona
	Context	<ul style="list-style-type: none">• New social housing project on a hilly terrain in north-eastern Barcelona
	Actors	<ul style="list-style-type: none">• Rainwater harvesting system to reduce street flooding and sewer overload and replenish aquifers• Department of Urban Planning (Barcelona City Council) and especially some planners with interests in these systems
	Instruments	<ul style="list-style-type: none">• Other city council agencies (water, parks and gardens)
	Processes/ dynamics	<ul style="list-style-type: none">• Funded by the city council• Initiated by the Barcelona City Council, top down• Initial reluctance by some actors (the water agency did not see Sustainable Urban Drainage Systems - SUDS - as safe enough)
SCdV	Outputs	<ul style="list-style-type: none">• Project led by a landscape architect
	Impacts	<ul style="list-style-type: none">• Gardened public areas to store and facilitate infiltration of rainwater• Reference for the drafting of a blueprint on “Good Practices” for SUDS in Barcelona
	Context	<ul style="list-style-type: none">• Wealthy Barcelona suburb with important outdoor water uses
	Actors	<ul style="list-style-type: none">• Sant Cugat City Council• Contractors and real estate agents
	Instruments	<ul style="list-style-type: none">• Companies installing URH systems
	Processes/ dynamics	<ul style="list-style-type: none">• Local ordinance to save water making URH systems mandatory for houses with gardens of a certain size• URH systems funded by homeowners• Initiated by the Sant Cugat City Council, top down
	Outputs	<ul style="list-style-type: none">• Thresholds for garden areas requiring an URH system lowered in successive versions of the ordinance
	Impacts	<ul style="list-style-type: none">• Reduction in the consumption of water from the public network (not quantified)• Model for other local policies on water retention in the Barcelona area

analytical categories of the theoretical framework developed out of the literature review: context, actors, instruments, processes/dynamics, outputs and impact. It draws on the entries in [Table 2](#), which summarises the nine cases in terms of these six categories, in order to develop cross-case interpretations of the data that relate to the existing literature on sociotechnical transitions and urban rainwater harvesting. For each of the six categories in turn we demonstrate how our empirical findings substantiate, challenge or transcend the state-of-the-art by using examples drawn from the nine cases. In doing so, we draw attention to some of the key challenges—but also opportunities—of mainstreaming rainwater harvesting in European cities: the principal purpose of the article.

1. *Context*: In line with recent research in human geography, in particular, the nine cases demonstrate the importance of local contextual conditions to the implementation of URH (Karvonen 2011). A favourable urban policy context proved hugely significant in advancing URH schemes in all three cities. Financial, political and/or legislative support by city councils and municipal administrations were often key to creating and sustaining the schemes. The physical geographies of each city certainly had a bearing on how rainwater harvesting has gained in importance, especially in Barcelona, yet urban development policy appears to have been a far more formative force. Two points of context are particularly noteworthy, as they are counter-intuitive and rarely addressed in other studies. Firstly, all but two of the schemes studied (ÅF and CC) were not primarily framed as urban rainwater harvesting projects. Rather, rainwater harvesting was always part of a larger scheme of urban development. This could be about creating a model urban quarter with integrated environmental solutions (as at HS), revitalising a low-income neighbourhood (as at JdP), improving the environmental quality of a street (as at HG) or nurturing the green image of an industrial estate (as at IL). Secondly, existing rainwater infrastructures did not feature significantly in many of the case studies, although infrastructural adaptation is a core theme of transitions research (Geels 2004). While the cases in Stockholm were designed to complement existing infrastructure, the URH technologies elsewhere were largely developed independent of a city's network of rainwater drains. The three Berlin projects, for instance, prioritised environmental standards in social housing (BS88), communal eco-living (SW) and savings on rainwater disposal charges (IL) over optimizing the city's rainwater sewer system. Overall, these findings are significant for indicating the wide-ranging potential of URHs to benefit from good connectivity to urban development priorities, but also the limitations of overlooking—deliberately or not—connectivity with existing urban infrastructures.
2. *Actors*: In terms of the key actors involved in promoting URH projects, it follows from the observation above that organisations responsible for rainwater infrastructure in each city—the water/wastewater utilities—rarely play a lead role in projects for rainwater harvesting. Rather, it is city departments with a remit for the environment or urban development that tend to be the driving forces of the schemes studied, supported by other public bodies such as housing associations, parks departments and transport authorities, as well as specialist engineering consultants. Water utilities are involved—if at all—only belatedly or indirectly in the planning process, enabling connections to the existing infrastructure or granting permits for alternative rainwater retention technologies. What also emerges from

the analysis is the dependence of several URH schemes on the initiative, expertise and persuasive powers of key individuals. This is evident in the cases of CC, SW, HS and HG, none of which would have emerged or developed without the dedication and determination of a small group of people. Their skills in convincing (sceptical) others to support their experiment and the trust they generated through their success proved invaluable. This resonates with much existing research on URH transitions (Bos and Brown 2012; Brown, Farrelly, and Loorbach 2013). Users of URHs were generally not involved in the design of URH schemes—especially in new, large-scale urban developments, such as HS or ÅF—but proved significant in subsequent practices. For instance, the ways in which shopkeepers at JdP have come to value the vertical gardens, residents at BS88 have stepped in to maintain their URHs and residents along HG express their appreciation of the greening project all illustrate the need to pay greater attention to users in future research on URH transitions.

3. *Instruments*: All nine of the URH projects studied are experiments that were made possible by the creation of niches for experimentation, in line with much transitions research (Schot and Geels 2008; Loorbach and Rotmans 2010). How these niches were created, and by what means they were advanced, varied hugely between the cities and projects that were studied. In the three Stockholm cases, a clear prevalence was given to environmental programmes and planning instruments: for instance, the formulated visions and master plans for a new urban development, statutory plans to embed these in a wider urban context and detailed engineering plans for on-site applications. In Barcelona, municipal ordinances have been used to good effect, notably in SCdV, where an innovative statute that requires rainwater retention on properties of a certain size has strongly driven the uptake of appropriate technologies on a large scale. Berlin, by contrast, offers examples of financial incentives for URH, in the form of a split tariff for rainwater that encouraged IKEA to retain and use rainwater at its new Lichtenberg store. It also illustrates, in the BS88 case, how ecological criteria for public funding schemes can incentivise the uptake of URH technologies. These findings highlight the variety of instruments available to promote URHs, but also the importance of local context in designing instruments to promote niche developments. They thereby substantiate recent research arguing for customised packages of incentives, rather than the application of a unitary instrumental tool-box (García Soler, Moss, and Papasozomenou 2018).
4. *Processes/dynamics*: The overarching observation on the processes of introducing URHs in the three cities is that none of the schemes remained as they were conceived, but changed—sometimes quite radically—in the course of implementation and use. Departures from the original plan could emerge as a result of increasing housing demand (as at ÅF), growing popularity of a perceived improvement to the urban landscape (as at HG and JdP) and changes in ownership of property (as was the case in BS88). These examples point to the (often unpredictable) dynamics of URH projects that need to be accommodated to achieve successful results. Even in instances where there were strong attempts to govern processes top-down through planning or regulatory authority (as at HS, ÅF, HG and SCdV), developments were not readily controllable and were challenged by several issues of uncertainty. This resonates with research into collective learning under conditions of complexity and uncertainty (Voß and Bornemann

2011). It also suggests, however, that the trajectories of URHs may well not fit into pre-ordained phases as defined in the literature—such as the linear model of pre-development, take-off, acceleration and stabilisation (Brown, Farrelly, and Loorbach 2013)—but are often messy, unpredictable and fluctuating.

5. *Outputs:* Given the early stage of several of the projects that were studied and the limited attention devoted to monitoring their performance so far, it is not easy to assess what they have achieved in terms of outputs directly attributable to each one. Self-assessments of water savings have been conducted in the cases of SW and IL, with both revealing impressive reductions in water use. The planning approach in the case of HS has influenced planning practices locally and contributed to the development of stormwater policy. However, appraisals of other outputs, especially non-technical ones, are largely missing. This blind spot is, of course, not exclusive to URH projects, but typical of most social-ecological innovations and in urgent need of in-depth research. Our own research revealed some significant sociotechnical achievements attained by the projects studied, even if they are hard to measure. Firstly, we note how the URH projects generated greater knowledge about, and acceptance for, alternative ways of dealing with rainwater in both professional circles and among the general public. People's attitudes and relationship to their urban environment changed significantly in the communal setting of SW, through the regulatory stipulations at SCdV and in recognition of the operability of alternative drainage at CC. Secondly, using and experiencing URHs can enrich people's sense of collective identity with a place, thereby enhancing its place-making qualities, whether it be a busy street (HG), a new urban district (HS) or a greened courtyard (JdP). URH proved an effective way of making environmental improvements visible, but also rendering urban landscapes more liveable.
6. *Impacts:* The wider impacts of each scheme are even harder to ascertain than the outputs. In almost all cases no form of impact assessment has been conducted (see Table 2). What we can highlight, on the basis of our own research, are early indications of what impact the schemes are having on the long-term process of mainstreaming URH in each city: the core issue of concern for this article. Here, we consider how far the technologies applied and experiences made in the nine case-study projects have been replicated elsewhere or up-scaled for broader applications in their respective cities. One good example is the municipal ordinance developed by SCdV to promote rainwater retention that has attracted wide interest nationally and may well be replicated in other communities facing similar rainwater shortfalls. The transformation of walls into vertical gardens at JdP has also been so well received that it has been standardised in order to be replicated elsewhere in the city. The code of "good practice" for URH developed at CC has already been used as a model for other projects in Barcelona. The specially structured soil developed at HG has set new standards in maximising rainwater retention by trees, but also generated a popular model for street landscape enhancement. On a broader scale, the HS scheme has proved inspirational for many other urban development projects locally, as well as globally (Ranhagen 2013; Hult 2015). In other cases, the wider impacts—in terms of replication or up-scaling—are less tangible. Experiences with URH technologies in all nine projects appear to be informing learning processes within the professional community, but this is difficult to pinpoint. What we can observe is that the projects implemented are rarely, if ever, copied exactly. Rather, selected elements

from them are taken up and adapted to new contexts. Given the uniqueness of each URH project—those in this article and generally—this is not at all surprising, but nonetheless highly significant when it comes to considering processes of technology dissemination and societal learning.

6. Conclusions

We return to the objective of this article and summarise the main findings regarding opportunities and challenges for mainstreaming URH projects. The article is distinctive for analysing and comparing nine cases of URH projects, which differ widely in terms of their driving forces, actor constellation, socio-spatial contexts, temporal dynamics and urban form. This diversity was analysed with a framework developed out of a multidisciplinary literature review that produced six analytical categories: context, actors, instruments, processes/dynamics, outputs and impacts. Through this analytical lens, the article broadened our understanding of the transition processes involved in promoting URH, revealing out of the systematic analysis key similarities and differences in the ways URH projects have been envisioned and pursued in the three cities.

The study underlined the interdependence and strong linkage between sustainable urban settlements and rainwater harvesting facilities. Moreover, a favourable urban policy context proved a crucial and formative force in advancing URH schemes. In line with research cited here, the study revealed the huge significance of political, financial and/or legal support. Within a supportive context, actors' agency and their persuasive power become another important facilitating factor for the advocacy of URH schemes, in particular in the critical phase from incubation to implementation.

What also emerges from the study is the vital role of water utilities in planning, designing and connecting URH facilities to existing rainwater/urban infrastructure. This role was found to be either overlooked or downplayed, resulting in undefined ownership and responsibilities, and compromised system performance and expected outcomes. However, the connectivity of URH projects to existing urban infrastructure in some cases proved significant for realising the wide-ranging benefits of these facilities and supported their potential for mainstreaming.

In line with much research (e.g. Cettner *et al.* 2013), the study also points to the prominent role of municipal planning and other instruments of the local state in creating and sustaining niches for experimentation. However, we found that the planning and implementation of URH schemes rarely remain as originally intended, but were often adapted to reflect new contingencies and altered goals. To help URH schemes across such volatile terrain, long-term support and commitment becomes a crucial factor, our research reveals, resonating with other findings from transitions research (Voß, Smith, and Grin 2009; Voß and Bornemann 2011).

Generalising from the outputs of the examined cases is not an easy task. Assessment of project outputs in terms of water savings and cost reductions proved clear in some cases, but was not assessed in others. Technical knowledge, standardisation and social learning of sustainable planning approaches were developed in several URH schemes, though often not institutionalised. The lack of sufficiently inclusive and democratic planning procedures and of a long-term commitment to public inclusion and education in designing and monitoring URH systems remain substantial challenges on the path towards more just and sustainable rainwater management systems. The diverse ways in which

URH schemes can generate a collective sense of place-making and identity, documented here, is indicative of the potential value of URH to enhance citizen/environment relations.

In terms of broader impacts, whether URHs can be mainstreamed into urban drainage systems, or are limited to mere demonstration projects, is hard to ascertain. The cases where the construction of URH amenities emerged through municipal planning processes showed some signs of mainstreaming, as manifested in models or standardised procedures that have acted as a source of inspiration for other projects and urban water policies. However, it is difficult to pinpoint the future direction of URHs, given the limits of generalisation from only nine largely experimental cases. Initial steps towards mainstreaming, the increasing number of implemented URH projects, the expanding circle of actors involved, as well as growing pressures from climate change are all likely to push these systems forward as complementary options for the sustainable management of rainwater in cities. The interplay between emerging pressures, context, agency and processes/dynamics will play a decisive role in determining the speed and direction of transition pathways for URH.

Finally, our study uncovered two blind spots in empirical research. The first is the need for in-depth research regarding the appraisal of outputs of URH schemes, assessing not only environmental performance but also non-technical factors, a deficit not exclusive to URH schemes but typical of many social-ecological innovations. The second is the need to pay greater attention to potential dissemination pathways for URH and their attendant governance arrangements, focussing not only on replication in other spatial contexts, but also on upscaling beyond the bounds of a sociotechnical experiment.

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